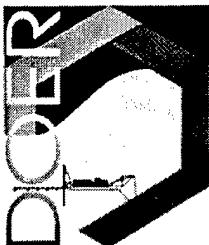


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Larval Fish Feeding Responses to Variable Suspended Sediment and Planktonic Prey Concentrations

PURPOSE: Understanding fish feeding responses under conditions that simulate turbidity plumes and variations in prey availability enhances the ability to predict ecological impacts from dredging projects. For example, in the context of nearshore placement of mixed sediments, concerns have been raised that winnowing of fine sediments from deposited dredged material may elevate turbidity and have a detrimental impact on early life history stages of fishes. The feeding responses of larval fishes to varying concentrations of suspended sediments and planktonic prey are reported herein.

BACKGROUND: There is little empirical information concerning how turbidity influences the behavior of estuarine and marine fishes under conditions that are typically encountered during dredging projects (Wilber and Clarke 2001). Suspended sediments cause turbidity by attenuating light through both particulate scattering and absorption (Wilber 1970). Reduced water clarity may affect fishes' abilities to forage, which if sufficiently curtailed, could prevent satisfaction of food requirements for their metabolism and growth. Fishes need sufficient light at depth to be able to detect food particles, which for larval fishes are viewed laterally and not vertically. Suspended sediments can mask or block light reflected horizontally, thereby reducing water clarity. Turbidity may also affect a predator's ability to detect and capture larval fish. Increased light attenuation caused by turbidity shortens the depth of the photic zone, which in turn affects primary production. Thus, turbidity may influence the productivity of fish stocks through a number of mechanisms. High turbidity can reduce feeding in adult Atlantic croaker (*Micropogonias undulatus*) and pinfish (*Lagodon rhomboides*) (Minello et al. 1987); however, potential impacts on larval fishes are not well understood.

Turbidity within a waterbody varies due to changes in soil composition, land development, agricultural practices, weather, and a host of other factors in the watershed. Turbidity at a given location can vary over time by orders of magnitude due to either natural (e.g., tidal resuspension, storm runoff) or anthropogenic (e.g., logging, dredging) disturbances. Likewise, plankton are patchily distributed, with concentrations varying over orders of magnitude within a few meters. In this study, the feeding success of five estuarine fish taxa exposed to varying turbidity and prey concentrations is examined. These experimental factors are varied over orders of magnitude so as to maximize opportunities to detect taxonomic differences in response to the two factors.

METHODS: Experimentally exposing fish larvae to controlled turbidities requires methods that compensate for the tendency of clay and silt particles to flocculate and settle out of suspension, making it difficult to maintain a specified turbidity for the duration of a test interval. Maintaining uniform prey densities also poses a challenge, because many planktonic organisms exhibit strong phototaxis. Therefore, in a static system, prey may aggregate with respect to an existing light

gradient, thereby influencing the ability of fish larvae to feed upon them. To deal with these problems, a testing apparatus was designed that consisted of a clear acrylic "wheel" partitioned into six chambers to hold seawater, sediment, fish and brine shrimp (*Artemia franciscana*) nauplii. Each chamber had a mean volume of 2.733 liters and had two access ports with expandable plugs for filling and draining. During a test, the wheel was slowly rotated on the vertical axis on a motorized base to maintain the sediment in suspension and to continuously alter the direction of light.

Fishes used in the experiments included spot (*Leiostomus xanthurus*), pinfish (*Lagodon rhomboides*), Atlantic croaker (*Micropogonias undulatus*), Atlantic menhaden (*Brevoortia tyrannus*), and flounder (*Paralichthys* spp.). Larval and young juvenile fishes were collected on flooding tides using a 945- μ m mesh net with a 1- \times 2-m opening and live-box attached to its terminal end. Fishes were held in flow-through tanks and were fed freshly hatched brine shrimp. Four total suspended sediment (TSS) concentrations (20, 200, 2000, and 20,000 mg/L) were created by blending the appropriate weight of pre-wetted kaolin clay with aerated and filtered seawater to form a slurry before each trial. Freshly hatched brine shrimp nauplii were used as prey in all of the experiments during the first phase of the study. Natural plankton assemblages were used in subsequent experiments to see if fish reacted differently to prey they were more likely to encounter in nature. Marine plankters were collected just prior to their introduction into the test apparatus. Three levels of brine shrimp concentration were used (1.0/ml, 0.1/ml, and 0.01/ml). An additional prey concentration of 0.001/ml was used for the experimental trials that used natural plankton.

Clay and prey concentrations were randomly assigned to the 12 chambers of the two wheels. Each wheel chamber was partially filled with filtered seawater while it was in a horizontal orientation. The assigned clay slurries were then poured into the chambers followed by the prey. Each chamber was filled to within 1-2 cm of the top with filtered seawater. Dissolved oxygen, temperature, and salinity were measured in one randomly selected chamber from each apparatus. A fish that had been held without food for 24 hr was then introduced to each chamber. The access ports were plugged and the two wheels were placed in a vertical orientation on top of a motorized roller system powered by a variable-speed motor. The wheels were set in motion at 3.5 rpm for 1 minute to resuspend any settled silt-clay, and then slowed to 1.75 rpm for a 30-minute feeding period. At the end of the feeding period, both wheels were removed from the motorized roller and the contents of each chamber were strained through a dip net to recover the fish, which were processed for gut content analyses. Fish prey consumption was recorded as 0, 1-9, 10-99, or 100+ prey items consumed.

Logistic regression models were applied to the data for each species and prey type. These analyses allow estimations of probabilities that a fish will feed under different levels of turbidity and food concentration. The parameter estimates for the models also provide a convenient means of making comparisons between species concerning the relative importance of turbidity and prey concentration in determining feeding success. The logistic regression models were fit to the logarithms of the sediment and prey concentrations.

RESULTS

Brine Shrimp Trials: The five fishes tested using brine shrimp exhibited different patterns in their response to the different turbidity and prey concentrations. Results of the logistic regression analyses are given in Table 1 and response surface information for each fish is presented in Figures 1-5. Tests of the null hypotheses were rejected for all fishes (all p-values < 0.05). The standardized estimates are useful for comparing the relative importance of the two factors (turbidity and prey concentration) in influencing whether a fish had fed. For example, in the case of pinfish, the two factors are nearly equivalent in the magnitude of their effects (standardized estimates, Table 1), whereas in the case of spot, the effect of prey concentration was more than twice the magnitude of the effect of turbidity.

Twenty percent of the menhaden fed during the trials (Table 1). Menhaden were most likely to feed at low TSS and high prey concentrations (Figure 1). The probability that menhaden fed dropped off sharply as both turbidity increased and prey concentrations decreased. More than half (56 percent) of the pinfish fed, exhibiting a response similar in magnitude for the two factors (Table 1). Some pinfish fed even at the highest TSS concentrations (Figure 2). Sixty-five percent of fish spot fed during the experiment. At the highest prey concentration, there was little reduction in the probability that fish had fed with increasing TSS concentration (Figure 3). Turbidity had the strongest effect on feeding at the lowest prey concentration; however, the effect of TSS was less than half that of prey concentration. Seventy percent of croakers fed, with the TSS and prey factors of similar importance, but of lower magnitude than for the other fishes (Table 1). As with spot, croaker had a high probability of feeding at the highest prey concentration irrespective of the turbidity level (Figure 4). Thirty-nine percent of the flounders fed, showing the strongest responses to both factors (Table 1) of any species tested. Flounders were most likely to feed at high prey concentrations and low TSS concentrations, with a rapid decline in feeding probability as these factors changed (Figure 5). Flounders did not feed at the highest TSS by lowest prey concentration combination.

Table 1
Logistic Regression Results for Fish Tested with Brine Shrimp Nauplii

Species	Mean Fish Size (mm)	N	Fed	p-value TSS	p-value Prey	St. Est. TSS	St. Est. Prey
Menhaden	24.6	265	54	0.0001	0.0001	-0.85	0.62
Pinfish	39.2	236	132	0.0001	0.0001	-0.53	0.54
Spot	30.2	252	163	0.0003	0.0001	-0.32	0.70
Croaker	12.4	165	117	0.0129	0.0032	-0.25	0.30
Flounders	11.9	381	150	0.0001	0.0001	-1.11	0.83

¹ P-values indicate chi-square probabilities. Standardized estimates are given for both the total suspended sediments (TSS) and prey factors.

Natural Plankton Assemblage Trials: The results of experiments in which plankton assemblages were used as prey are not as easily interpreted because of lower replication and the prey concentrations were a random rather than fixed factor in the statistical analyses. The planktonic prey were comprised of several species and life history stages. Results of the logistic regressions indicate that menhaden feeding success was significantly and inversely related to TSS concentrations, whereas it was not significantly related to the prey assemblage

concentration (Table 2). A higher percentage of menhaden fed on wild plankton (31 percent) than on brine shrimp (20 percent). Spot also had a greater tendency to feed upon wild plankton (74 percent) than on brine shrimp (65 percent). The model parameter estimates were relatively close to those observed for the brine shrimp logistic regression models with prey concentration being more influential than turbidity. A lower percentage of flounders (31 percent) fed on wild plankton than on the brine shrimp (39 percent), however, the parameter estimates were similar for the two logistic regression models for this fish taxon.

Table 2
Logistic Regression Results for Fish Tested with Wild Plankton Assemblages

Species	N	Fed	p-value TSS	p-value Prey	St. Est. TSS	St. Est. Prey
Menhaden	108	33	0.0001	0.0717	-0.86	0.26
Spot	102	76	0.0698	0.0001	-0.26	0.67
Flounders	108	34	0.0001	0.0001	-0.96	0.76

CONCLUSIONS: Results of these experiments demonstrate that prey and suspended sediment concentrations affect estuarine fish foraging success differently for different species. Of the fish taxa tested, paralichthid flounder exhibited the greatest sensitivity to variations in the combined variables. Flounder fed when TSS concentrations were low and prey concentrations were high and did not feed when these conditions were reversed (Figure 5). Menhaden exhibited a similar response profile (Figure 1). However, menhaden did consume some prey at the highest turbidity levels. Pinfish, spot, and croaker did not curtail feeding as much in response to increasing TSS concentrations (Figures 2-4) and were able to feed at the highest TSS concentrations when prey concentrations were also high.

The two highest TSS concentrations (2,000 mg/L and 20,000 mg/L) used in these experiments greatly exceed suspended sediment concentrations that are commonly associated with most dredging projects (Wilber and Clarke 2001), except within short distances from the source (e.g., bucket transversing the water column or immediately adjacent to pipeline discharges or hopper barge dumps). Other studies of larval estuarine fish responses to suspended sediments also report adverse impacts at very high TSS concentrations. For instance, larval Pacific herring *Clupea harengus pallasi*, reduce feeding when held at a TSS concentration of 2,000 mg/l for one day (Boehlert and Morgan 1985) and larval Atlantic herring larvae exposed to TSS concentrations of 19,000 mg/l for 48 hr suffered 100 percent mortality (Messieh et al. 1981). Results of this study indicate prey availability interacts with TSS concentration to affect fish feeding success on a species-by-species basis. When predicting the potential impact of elevated turbidity levels, consideration must be given to how different fish taxa detect and capture prey. For instance, it is not evident whether reduced visual acuity or physical contact with suspended particles, which may clog gill tissue, was responsible for reduced feeding rates.

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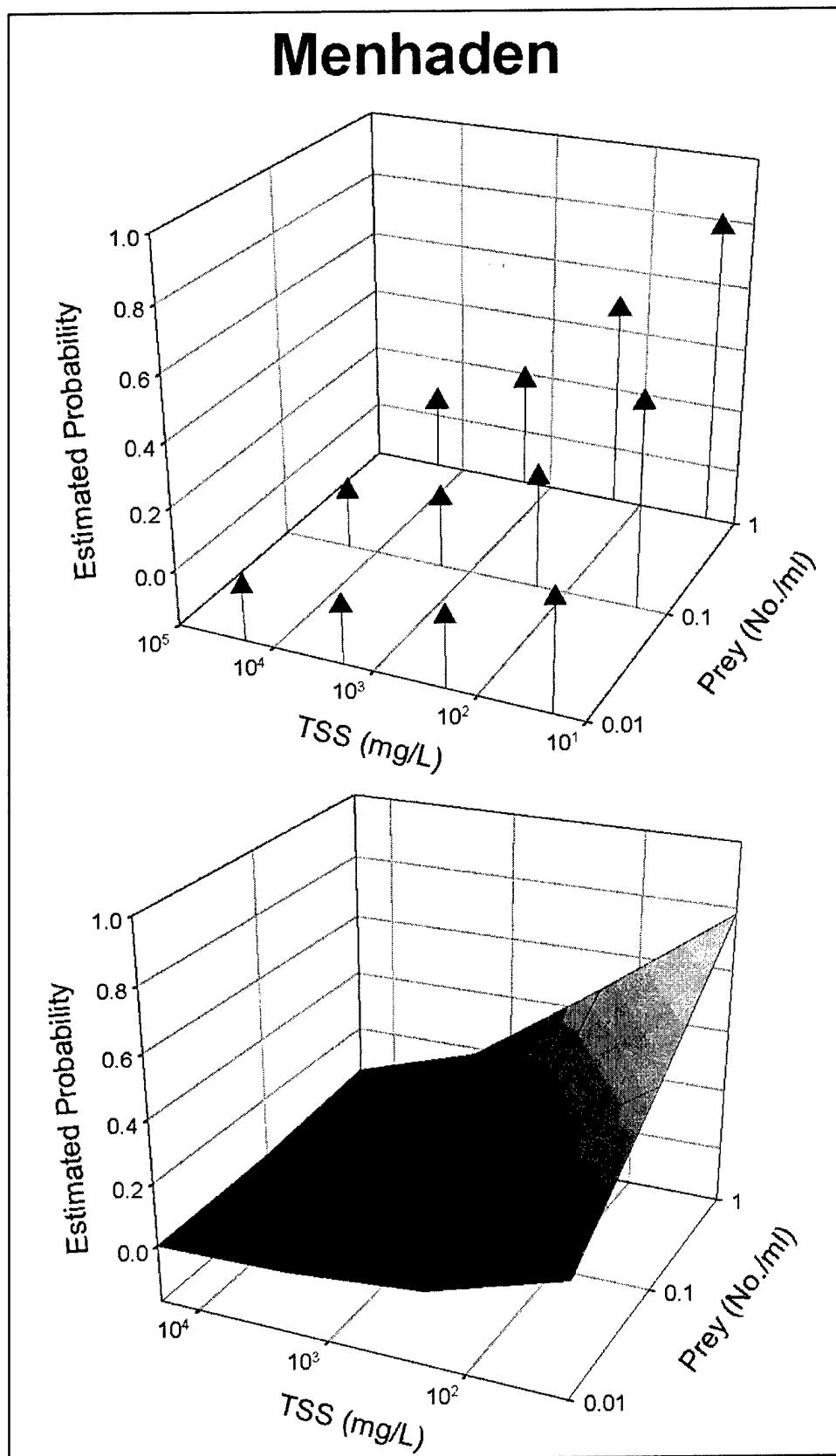


Figure 1. Response surface for larval menhaden prey ingestion versus TSS

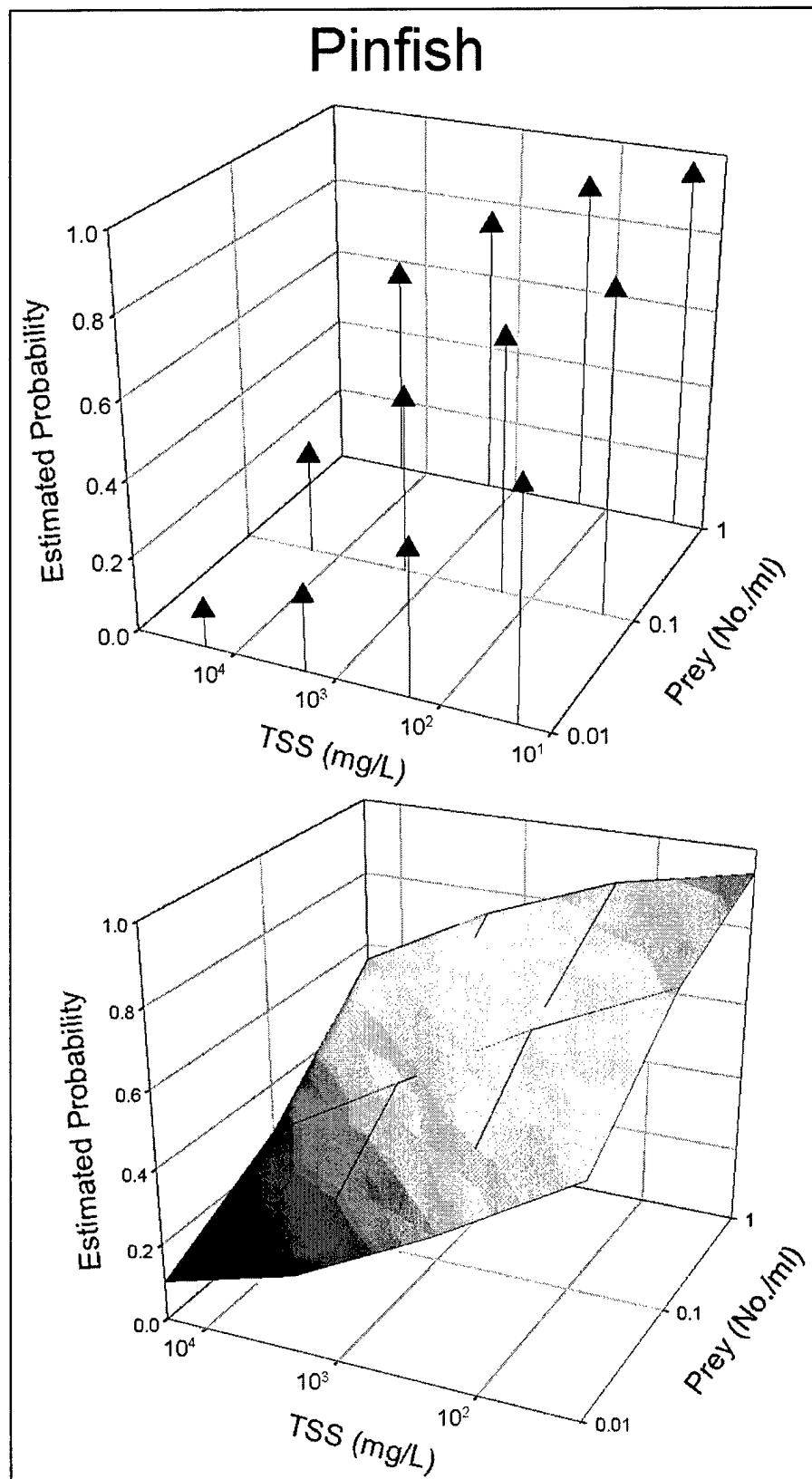


Figure 2. Response surface for larval pinfish prey ingestion versus TSS

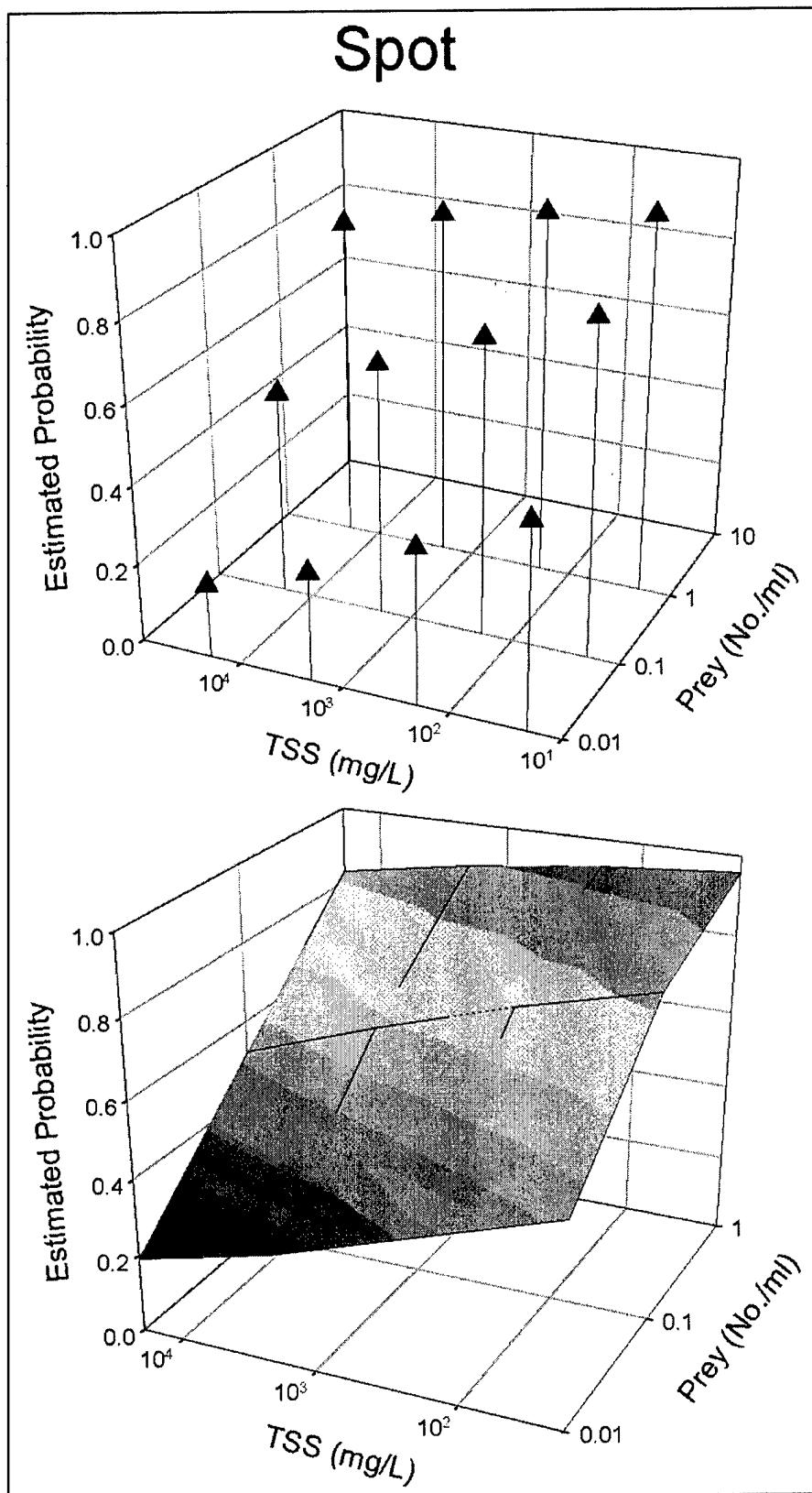


Figure 3. Response surface for larval spot prey ingestion versus TSS

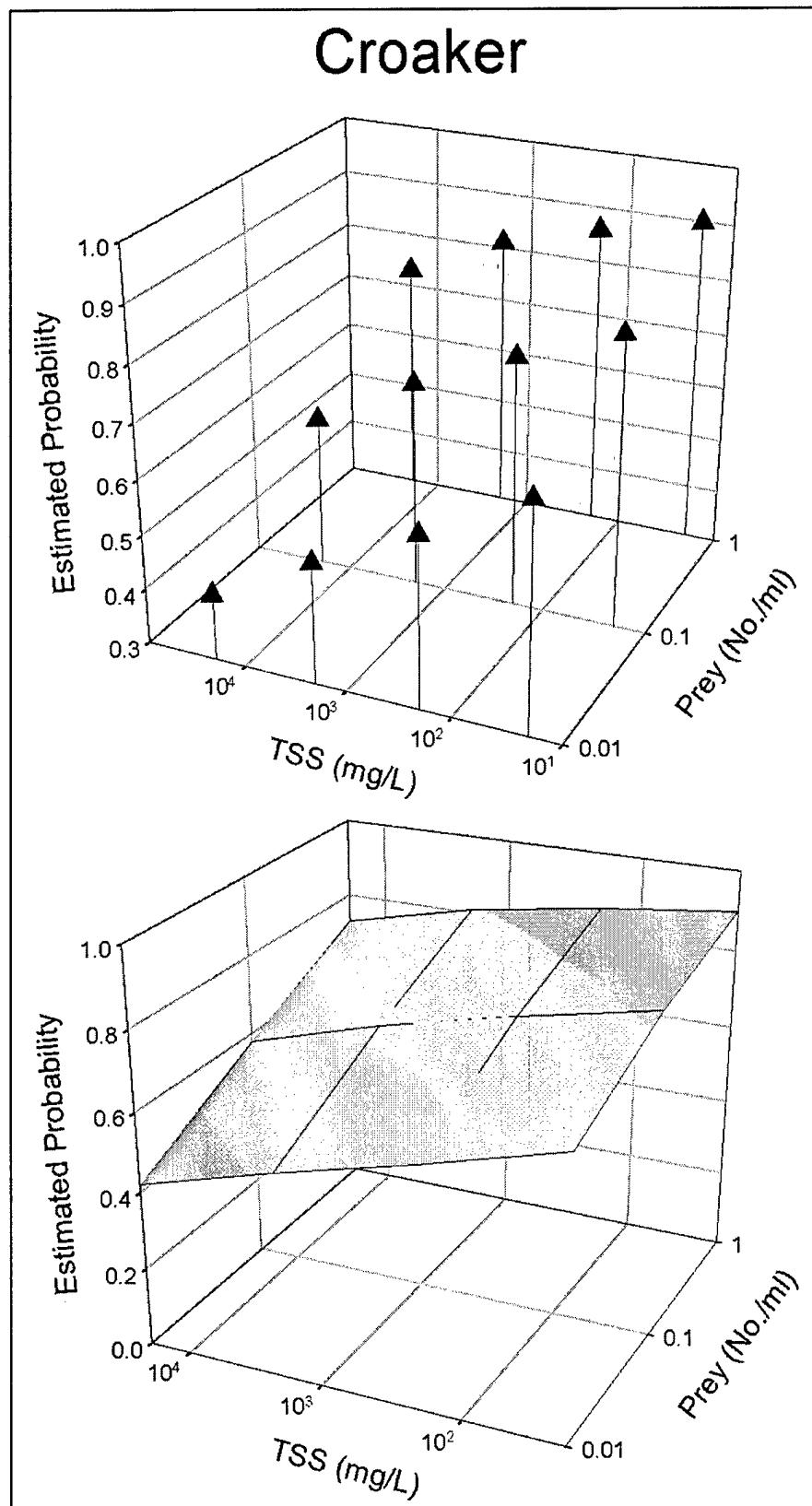


Figure 4. Response surface for larval Atlantic croaker prey ingestion versus TSS

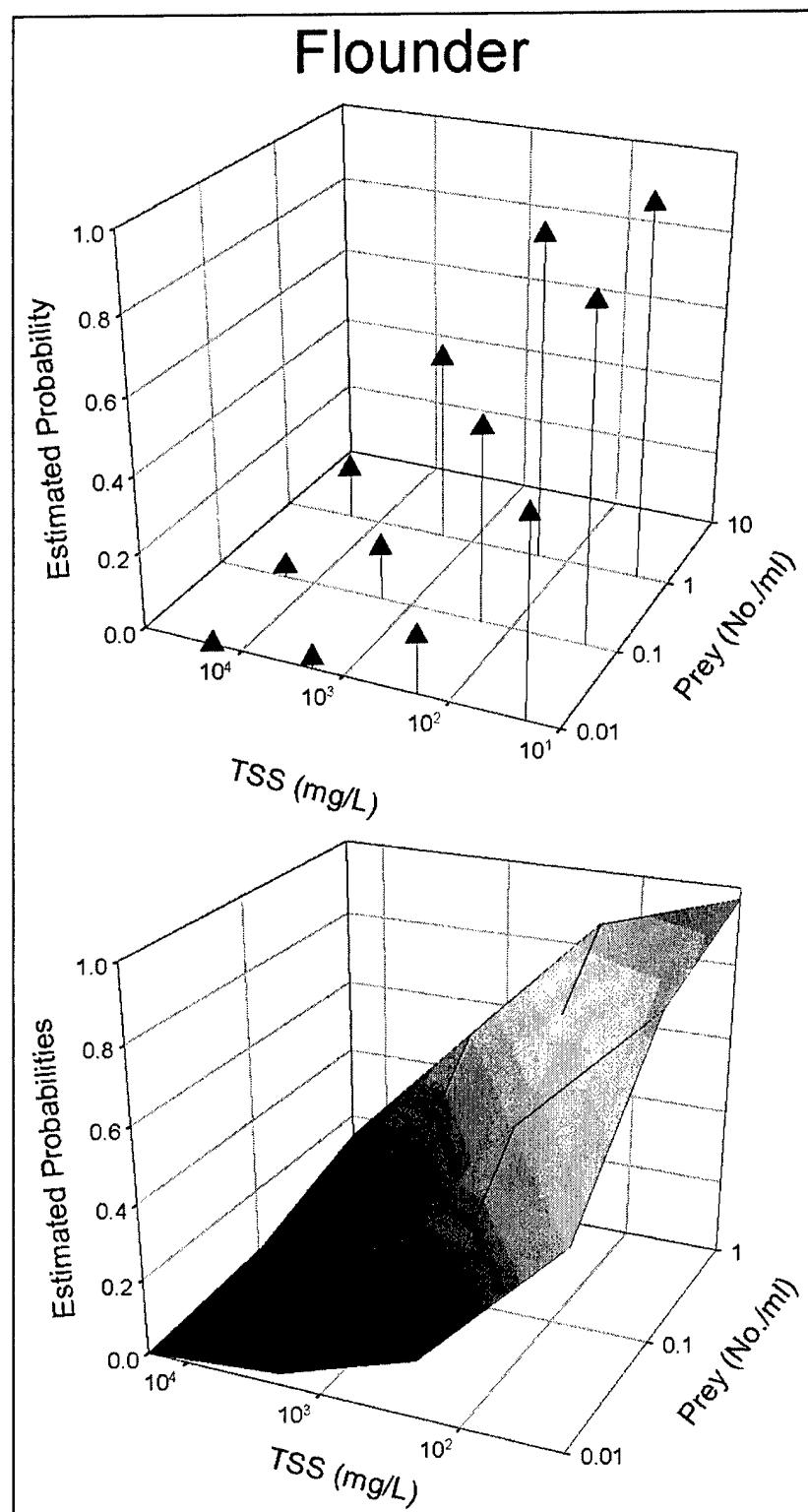


Figure 5. Response surface for larval flounder prey ingestion versus TSS

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